Spatial/Temporal Interdependence of Aftershocks Following the 10/31/2001 M5.1 Anza Earthquake

03HQGR0078

Dr. Frank L. Vernon III

Scripps Institution of Oceanography/IGPP MC 0225
University of California, San Diego
La Jolla, California 92093-0225 USA
Tele: (858) 534-5537 FAX: (858) 534-6354
E-mail: flvernon@ucsd.edu

December 1, 2004

Key Words: Fault Segmentation, Source characteristics, Fault stress interactions

Spatial/Temporal Interdependence of Aftershocks Following the 10/31/2001 M_L5.1 Anza Earthquake

1.0 Investigations undertaken

During this reporting period (October 1, 2003 through September 30, 2004) we have focused primarily on addressing the second task of our proposal, which investigates the temporal behavior of the 10/31/2001 ANZA M_L5.1 aftershock sequence (Figure 1). Our goal is to quantify the delay times between the mainshock and subsequent aftershocks. (Note that our previous report covered task number one, pertaining to the observed bimodal magnitude distribution). We are also in the initial stages of investigating the cause of the void in seismicity, which demarks an 'X', within the cluster of aftershocks from the M_L5.1 earthquake.

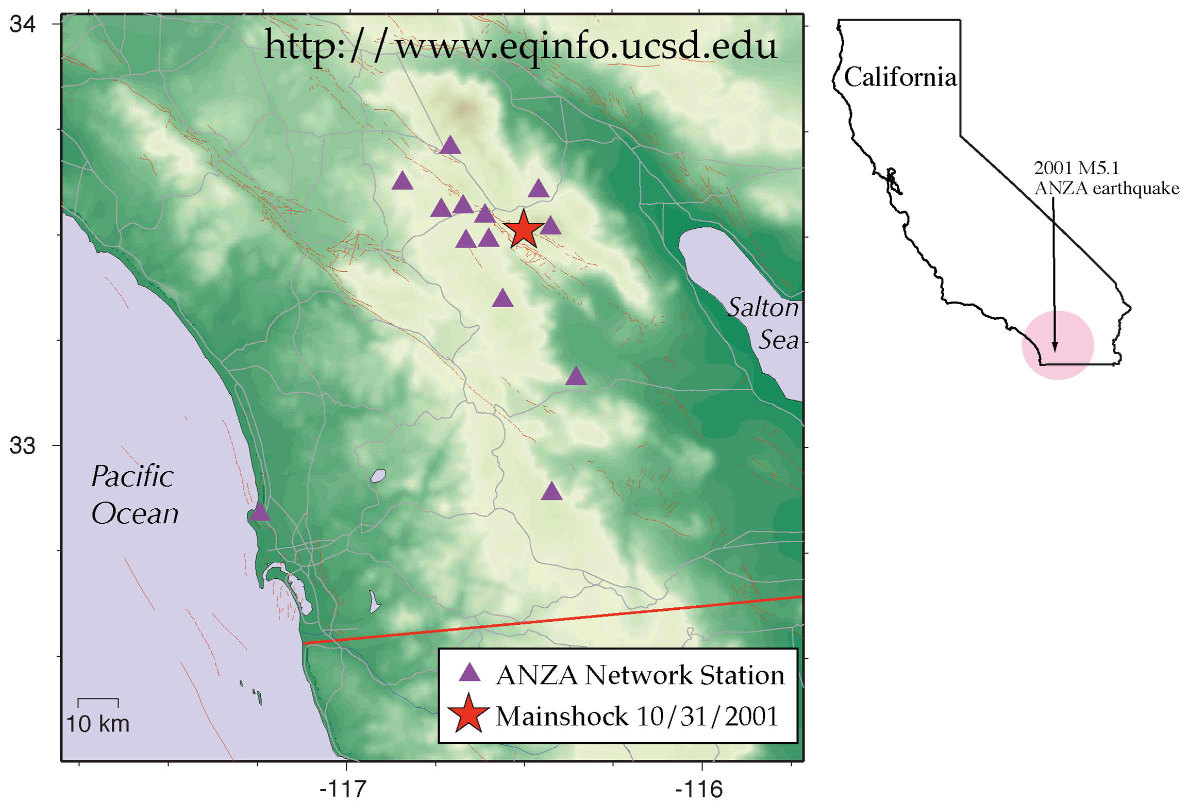

Figure 1. The location of the 10/31/2001 ANZA M_L5.1 mainshock earthquake (star) in southern California, and its spatial relationship with the ANZA seismic network stations (triangles). Note that 8 stations are within 20 km of the mainshock event.

Goals for this reporting period include:

- Identification of the first aftershocks in the M_L5.1 sequence.
- Quantifying how many stations recorded each aftershock.
- Determining the time lag between the mainshock and the initial aftershocks.
- Identifying the average time between aftershocks in the initial part of the sequence.
- Estimating the distance/magnitude detection capabilities.
- Quantifying the detection capabilities of smaller earthquakes juxtaposed in the coda wave of larger earthquakes.

2.0 Results

The temporal behavior of aftershocks in the initial portion of the M_L5.1 earthquake sequence: It is difficult to identify aftershocks in the initial part of an aftershock sequence for a number of reasons including aftershocks obscured in the coda of the mainshock, errors in unraveling seismic waveforms of temporally overprinted events, minimal signal to noise ratios for small events, events with large source/station distances and/or limited recording bandwidth. These difficulties often make it impossible to identify clearly the onset of the aftershock sequence.

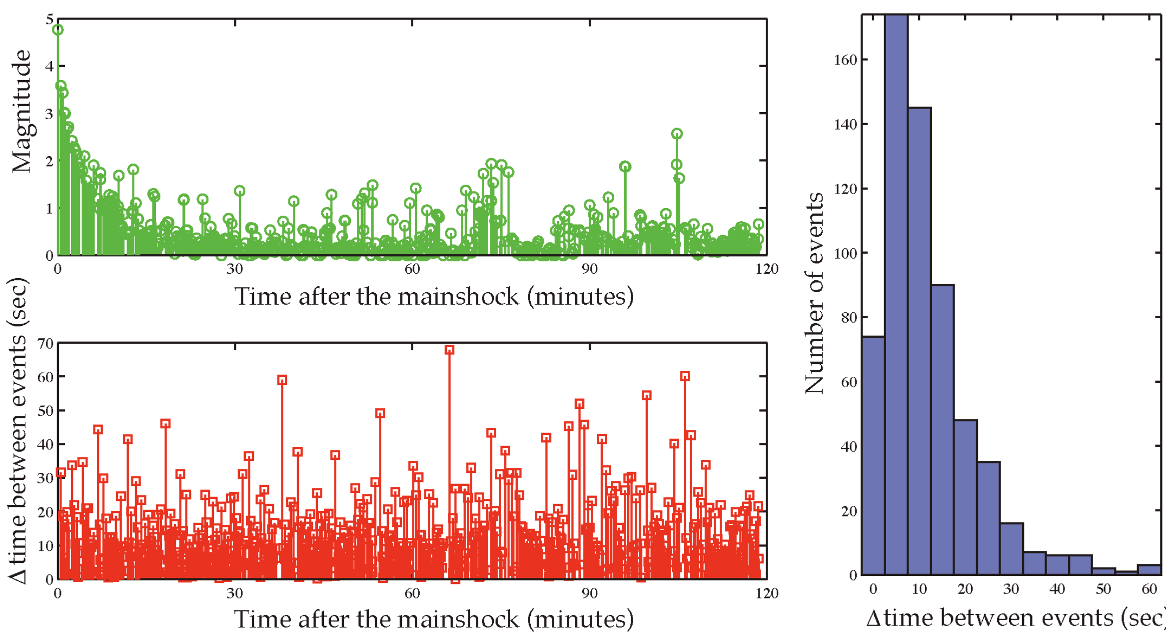

Figure 2. Temporal behavior of the first 599 aftershocks in the ANZA M_L5.1 sequence. In the first two hours of the sequence the mean time between successive aftershocks is ~7 seconds.

The ANZA broadband network's (http://www.eqinfo.ucsd.edu) recording of the 31 October 2001 M_L 5.1 sequence avoids many of the detection problems listed above because the mainshock was directly below the network, which recorded continuous waveform data at 12 azimuthally well-distributed stations about the study region (eight of these had hypocentral distances < 20 km). A high pass filter (*e.g.*, f > 1.0 Hz) was used to identify seismic arrival times of the aftershocks and in turn determine the aftershock locations. In this way, we cataloged 599 events ($0<M_L<2.5$) in the initial two hours of this sequence. For these events, the average time between aftershocks was ~7 seconds (Figure 2). In the broadband data we find only one detectable aftershock in the first two minutes of the continuous waveforms; however, on the short period records at one of the closest stations, TRO, we can identify an additional event 15 seconds into the sequence (Table 1).

To quantify our detection capabilities we estimate when aftershocks of different magnitudes can be identified within the mainshock coda. To do this, at each station, we compute the maximum amplitude of 200 representative aftershocks of various magnitudes (Figure 3) and then determine the time when each amplitude exceeds the envelop of the mainshock coda (computed using a Hilbert transformation). We are fairly confident that > M_L 1.5 events 45 seconds or longer after the mainshock should be detectable, which suggests that the lack of seismicity in the 45 second-2.0 minute range is potentially real (see Figures 4 and 5).

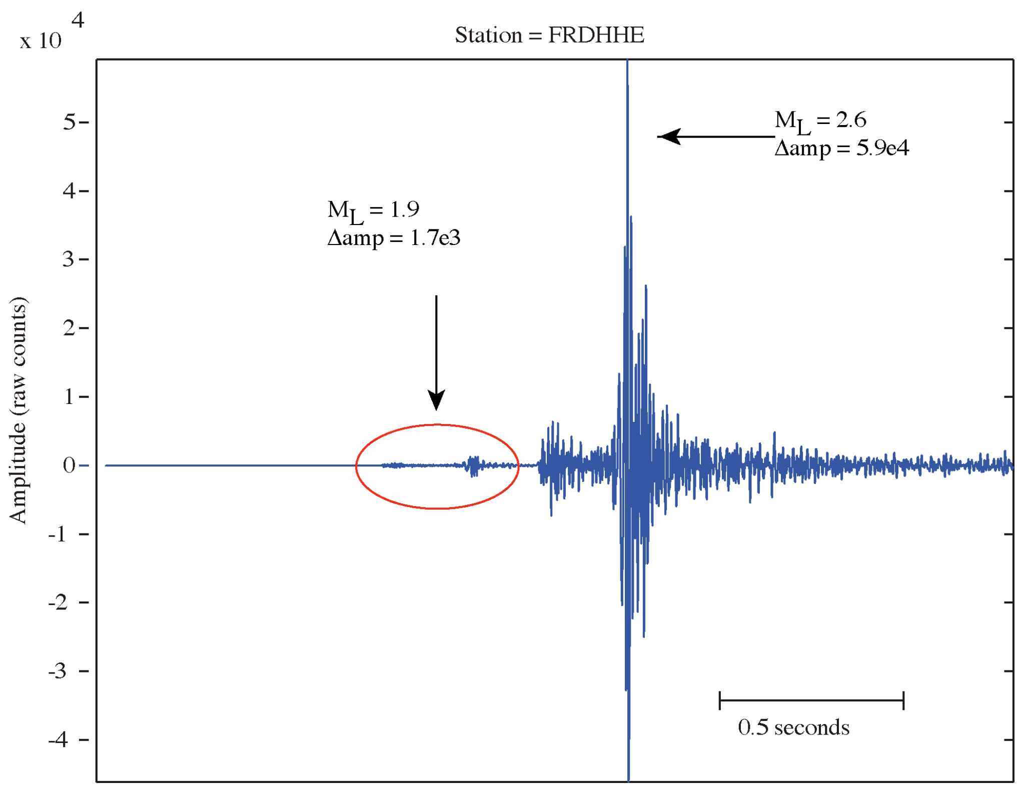

Figure 3. Seismic recording at ANZA station FRD of two earthquakes: a magnitude 1.9 earthquake followed almost immediately by a magnitude 2.6 earthquake. If the magnitude 1.9 event instead occurred in the coda of the 2.6 event, its signal would be obscured and detecting it would be challenging.

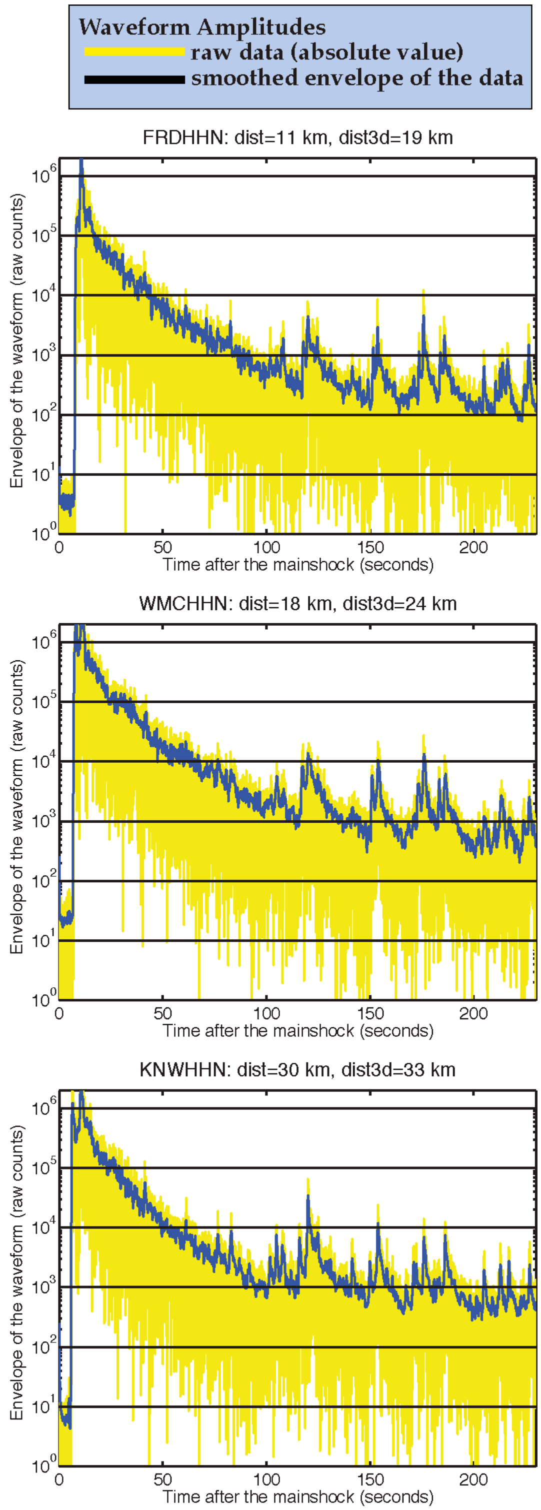

Figure 4. Envelope of the mainshock coda (computed using a Hilbert transform) recorded at three ANZA network stations FRD, WMC, KNW, which were located at mainshock hypocentral distances of 11, 18 and 30 km, respectively. The coherence across the three stations of an elevated amplitude within the coda signal at ~110 seconds, 150 seconds and 220 seconds helps to identify aftershocks at these times.

Table 1. Identification of the first observable aftershocks in the M_L5.1 ANZA aftershock sequence. Also listed are the elapsed time between the mainshock and aftershock of interest (Δt) and the elapsed time between subsequent earthquakes (Δlag).

Station	Epi-Distance (km)	Hypo-Distance (km)	*Main-shock*	Event #1	Event #2	Event #3	Event #4	Event #5	Event #6	Event #7	Event #8
Mag			*Ml=5.1*	Ml < 3.0	M≅2.6	M≅2.4	M≅2.0	M≅1.9	M≅1.9	M≅1.7	M≅2.2
Δt (sec)			*0.0 sec*	15.0 sec	31.6 sec	50.3 sec	66.6 sec	73 sec	93 sec	94.5 sec	110. sec
Δlag (s)			*0.0 sec*	15.0 sec	16.6 sec	18.7 sec	16.3 sec	6.4 sec	19.9 sec	1.6 sec	15.5 sec
TRO	6.206	16.601	YES	YES	YES	N/A	YES	YES	YES	YES	YES
PFO	10.523	18.650	YES	YES	YES	YES	YES	YES	YES	YES	YES
FRD	10.580	18.682	YES	--	YES	YES	YES	YES	YES	YES	YES
SND	11.661	19.315	YES	--	--	YES	YES	YES	YES	YES	YES
BZN	16.504	22.571	YES	--	--	YES	YES	YES	YES	YES	YES
WMC	17.853	23.576	YES	--	--	YES	YES	YES	YES	YES	YES
LVA2	19.913	25.172	YES	--	--	--	YES	YES	YES	YES	YES
CRY	23.205	27.848	YES	--	--	--	YES	YES	YES	YES	YES
KNW	29.537	33.310	YES	--	--	--	--	--	YES	YES	YES
RDM	35.060	38.292	YES	--	--	--	--	--	YES	YES	YES
MONP	70.190	71.859	YES	--	--	--	--	--	--	--	--
THSB	98.845	100.037	YES	--	--	--	--	--	--	--	--
SOL	103.26	104.402	YES	--	--	--	--	--	--	--	--

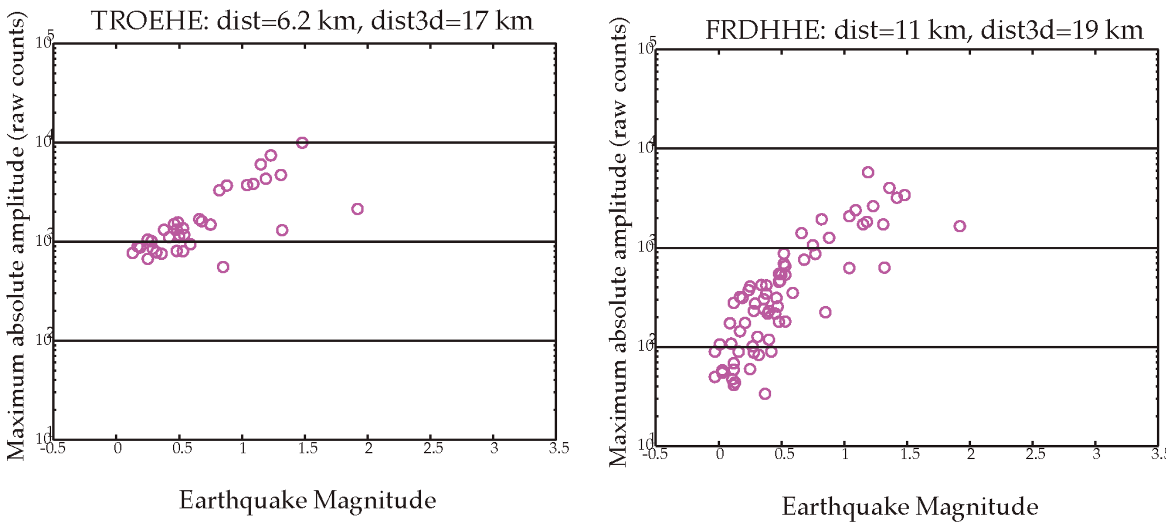

Figure 5. Quantifying the maximum amplitude (in counts) of broadband recordings of seismic waves (primarily dominated by the S-wave) as a function of earthquake magnitude.

Using the amplitude of 100 representative aftershocks as a guide, we find aftershocks are more easily identified at stations with small source/station distances (*e.g.*, station TRO), as well as stations where the mainshock coda falls off relatively rapidly (*e.g.*, station FRD) (see Figure 5).

Summary of our Results:

High Quality Data: It is rare that we have an opportunity to record a sizable earthquake (M_L>5) on a broadband network that is azimuthally well distributed about the study region and near to the earthquake source (*i.e.,* in this study 8 are < 20 km from the mainshock).

Detection Capabilities: We estimate detectable aftershocks within the mainshock coda include those that are approximately:

- M_L>2.5, Δdist<10 km, Δtime >15 seconds
- M_L>2.0, Δdist<30 km, Δtime >50 seconds
- M_L>1.0, Δdist<50 km, Δtime >60 seconds

These values are dependent on the source/stations distance (Δdist) and the time of occurrence after the mainshock (Δtime), in addition to the mainshock and aftershock focal mechanisms. Additionally, coherence of the signal across multiple stations can help in detecting small events.

Identified Aftershocks: In the broadband data we find eight detectable aftershocks (1.7< Ml < 2.6) in the first 2 minutes of the continuous waveforms. However, if we were limited to stations >30 km from the mainshock, only 3 of these earthquakes would likely have been detected.

Mainshock/Aftershock Lag Time: We expect that aftershocks of magnitude 1.5 or below are not detectable by the ANZA network in the initial ~50 seconds of the coda wave, which might contribute to any apparent lack of aftershocks in the initial part of the aftershock sequence in comparison with an Omori 1/t aftershock decay rate.

In Agreement with Previous Results: With careful filtering 'missed aftershocks' (*i.e.,* those not identified by routine processing) can be identified within the mainshock coda (*e.g.,* Vidale *et al.,* 2003).

3.0 Non-technical Summary

We find eight detectable aftershocks (1.7<M_L<2.6) in the first two minutes of the continuous waveforms from the 10/31/2001 M_L5.1 aftershock sequence (hypocentral distances < 20 km for 8 stations). However, if we were limited to stations >30 km from the mainshock, only 3 of these earthquakes would likely be detected. Identification of aftershocks in the initial part of the sequence depends on the source/station distance (Δdist), time elapsed since the mainshock (Δtime), and the mainshock and aftershock focal mechanisms. We estimate detectable aftershocks within the mainshock coda includes aftershocks that are approximately: M_L>2.5, Δdist<10 km, Δtime>15s; M_L>2.0, Δdist<30 km, Δtime>50s.

4.0 Reports published

These data and results were discussed at the SSA meeting (April, 2004) and the Brune symposium (November, 2004):

Kilb, D., Martynov, V., and F. Vernon, Examination of the Temporal Lag Between the 31 October 2001 Anza, California, M 5.1 Mainshock and the First Aftershocks Recorded by the Anza Seismic Network. SSA abstract 04-149, G6, 2004.

Vernon, F. *et al.,* Review of ANZA Seismic network, Research and Unanticipated Directions, J. Brune Symposium, Reno, NV, November, 2004.

5.0 Availability of seismic data

We have a world-wide-web home-page for the ANZA network, http://eqinfo.ucsd.edu, which provides maps and information about our database, stations, hardware configurations, including all network metadata in dataless seed volumes. We make special event web pages (http://eqinfo.ucsd.edu/special_events/index.html) for significant local, regional, and teleseismic events and maintain our *dbrecenteqs* webpages showing the latest seismicity on local, regional, and global scales (*e.g.,* http://eqinfo.ucsd.edu/dbrecenteqs/anza/AZ_R2_map.html). The complete waveform data set of the ANZA network data, which consists of over 58,180 events, is stored on-line on a RAID mass storage. These data are stored in the standard CSS 3.0 format complete with instrument responses and they are accessible over the Internet. A data request is satisfied by placing the data in a directory for retrieval via the Internet or by sending a tape copy. Additional information can be obtained by sending email to anzanet@epicenter.ucsd.edu. At present we provide data in the following formats: CSS 3.0, SAC, or SEED. The IRIS Data Management Center is maintaining a complete copy of our data archive (updated in real-time) and ANZA data is integrated into their standard FARM database and BUD real-time data distributions. Researchers from academia and industry have complete access to all ANZA data and results directly through UCSD or can access data through the SCEC Datacenter or the IRIS DMC.